# Positron Production and Capture based on Low Energy Electrons for SuperB

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# POSITRON PRODUCTION AND CAPTURE BASED ON LOW ENERGY ELECTRONS FOR SUPERB

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*Abstract*

Providing a high quality and sufficient high current positron beam for the ultra high luminosity B-factory SuperB is a major goal. In this paper a proposition for positrons production and capture scheme based on low energy electrons up to 1 GeV is presented. For this technique, several types of flux concentrator used to capture the positrons are being studied. The following accelerating section bringing the positrons up to 280 MeV and the total yield for L-band and S-band type accelerators are given. Also the result of the benchmark between ASTRA and a LAL code based on Geant4 toolkit simulation is discussed.

## INTRODUCTION

At the SuperB B-factory, the injection requirements rate in the High and Low Energy Rings (HER and LER) and the injection acceptance of the Damping Ring (DR) impose a source of positron of high quality and sufficient intensity [1]. The total length and cost suggest to use a positron source based on a low energy drive beam which can respond to the SuperB requirements [2].

In the following report, we evaluate the impact of using a low energy drive beam (~600 MeV) with a combination of a capture scheme based on various cavity phase strategy before being reaccelerated up to the DR.

## GENERAL LAYOUT

The general layout for the low energy positron source is shown in Fig. 1. The positrons are created within a target downstream an electron drive beam, are then captured in an Adiabatic Matching Device (AMD) and accelerated with a pre-injector encapsulated in a solenoidal field. A conventional accelerator is then used to bring the positrons up to the DR energy.

### *General Layout*

The electrons are accelerated by a drive beam up to 600 MeV on to a tungsten target of 1.04 cm thickness. The yield, i.e. the number of positrons per electron, is 1.7 e+/e- (Geant4 simulation [3]). This yield increases linearly with the incoming electron beam energy e.g. ~1.95 for 700 MeV electrons. The 10 ps long positron bunch out of the target acquires a large angular and energy distribution due to the successive bremsstrahlung, multiple scattering and pair creation processes occurring within the target.

In order to decrease the transverse emittance of the positrons, it is foreseen to use an Adiabatic Matching Device.

### *Adiabatic Matching Device*

The AMD is constituted of several coils, based on a slowly decreasing magnetic field and allows an improved yield having a wide momentum range acceptance. The present AMD is 50 cm long with a longitudinal magnetic field starting at 6 T and decreasing down to 0.5 T, which is the strength of the solenoid encapsulating the downstream accelerating section.

The AMD is simulated using ASTRA [4] with an analytic description of the longitudinal field [5]. The radial field is calculated within ASTRA. The positrons energy distribution at the exit of the AMD as a function of the longitudinal coordinate with respect to the reference particle is shown in Fig. 2. The longitudinal z-distribution with $z_{rms}$=2.3 cm gives a large tail for low energy particles.

The total yield of such system is given is Tab. 1. Preliminary studies indicate the use of a slightly shorter AMD field of 20 cm in length can decrease the longitudinal distribution to $z_{rms}$=1.5 cm. It potentially further improves the yield at the end of the downstream accelerating capture section.

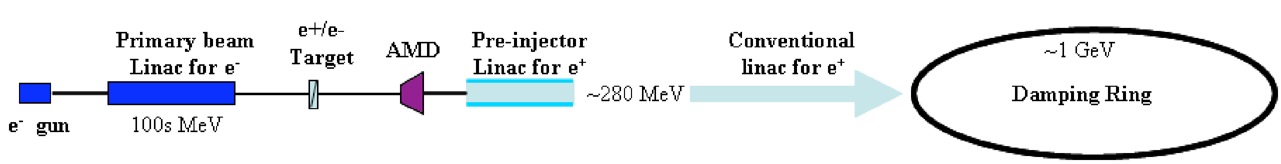


Figure 1: The basic layout of the positron source, including the electron drive beam, the target, the adiabatic matching device and the capture and accelerating section bringing the positrons up to ~300 MeV.

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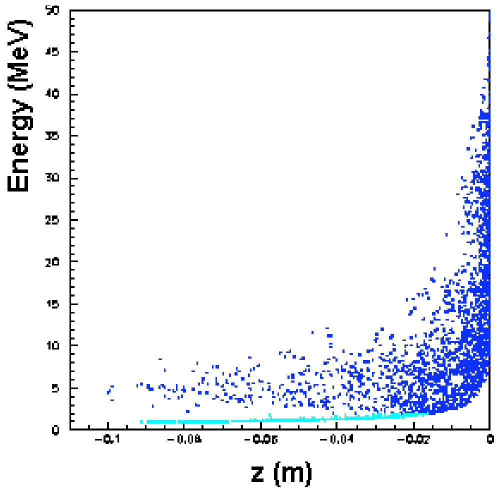


Figure 2: Longitudinal phase space distribution at the exit of the 6 - 0.5 Tesla, 50 cm long AMD.

Table 1: The total yield, longitudinal rms values and yield for positrons within the rms length for two types of 6 Tesla AMD (50 and 20 cm long).

| AMD type | 6T – 50 cm long | 6T – 20 cm long |
|---|---|---|
| Total yield | 71% | 77% |
| $Z_{rms}$ (cm) | 2.3 | 1.5 |
| Yield for particles $z<z_{rms}$ | 52% | 61% |

Additionally, a first benchmark between ASTRA and a LAL code based on Geant4 has shown a good transverse emittance agreement and a total yield for Geant4 of 64% for the 6T 50 cm AMD case. The main difference comes from low energy particles in the longitudinal tail within ASTRA.

## *Capture and Accelerating Section*

The accelerating structures of the SuperB linac are travelling wave (TW), constant gradient (CG), $2\pi/3$. They are made of a series of 86 RF copper cells, including couplers and constitute a full tank. The total length of a tank is for a standard SLAC type 2.856 GHz cavity, 3.054 m long as shown in Fig. 3.

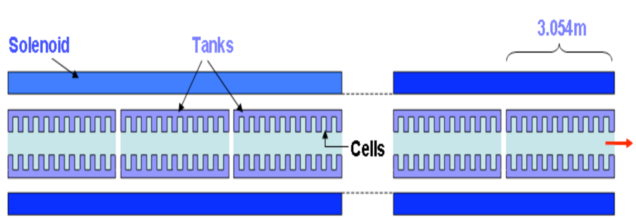


Figure 3: The 2.856 GHz 3.054m long tanks after the AMD encapsulated in a 0.5 T solenoid field.

## *Capture Approach*

Traditionally positrons are accelerated straight out of the AMD, using a cavity peak gradient as high as available. Additionally, an other approach is studied based on decelerating first the positrons to collect them in the first tank and then accelerate the particles in the subsequent tanks. This second approach requires adapting the gradient strength of the first tank in order to decelerate the positrons to bunch them with a small energy and longitudinal spread. Thus the peak gradient is lowered down to 10 MV/m. This technique is described in [6]. The phase of the cavity has to be tuned for this purpose, generally around 280°. Figure 4 gives the longitudinal distribution of the bunch after deceleration for two different cavity phases 200° and 280°. For this latter phase, the bunch length is much shorter. Additionally, several bunches are created within the accelerating section due to the long bunch entering the cavity. The choice of an appropriate phase helps to mitigate the number of positrons within these bunches.

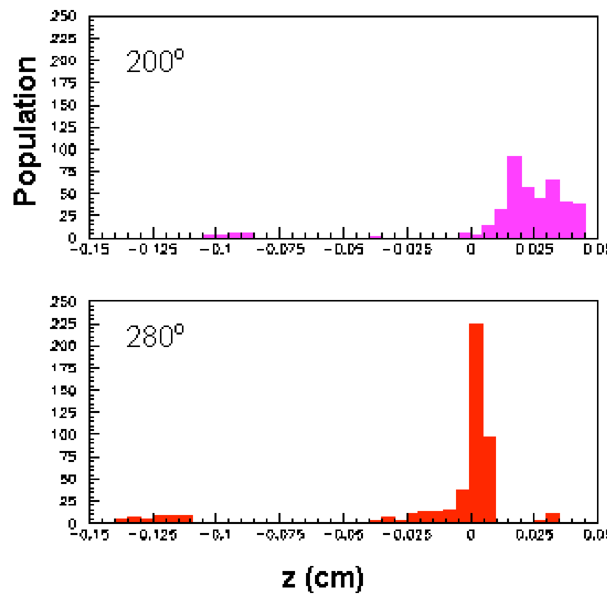


Figure 4: Typical longitudinal distribution of the bunch at the end of the first tank used for deceleration. Here cavity phases have been tuned at 200° and 280°.

## *Further Scenario*

In addition to the S-band scenario, several scenarios are under investigation such as L-band and L-band with higher mode.

The use of the standard SLAC cavities, strongly reduces the geometrical acceptance of the system due to the small radius of the cavity iris (~0.95 cm). So, to increase the geometrical acceptance, the capture in a L-band system is studied. To maintain the harmonic of the SLAC cavities a new design of a 1.428 GHz cavity is produced. For this, the cavity iris is 2 cm of radius and the tank length is 6.1 m.

Finally, a new idea is studied where a L-band capture [7] is performed but the first cavity is operated in the TM020 mode i.e. the actual RF is 3 GHz. This allows to keep a large iris aperture and a short wavelength. This later increases the bunching efficiency by decelerating positrons within a short length and wavelength.

### *Acceleration up to the DR*

Downstream the accelerating capture section bringing the positrons up to approximately 280 MeV, a more traditional linear accelerator is devised. It is constituted of a matching section followed by 2 m long FODO lattices. The quadrupoles of the matching section are 0.25 m long while the single quadrupoles of the FODO lattice are 0.265 m long. This section is used to accelerate the positrons up to the DR at the energy of the order of 1 GeV with an energy acceptance of 1%, i.e. ±10 MeV.

This section, using bends for $e^+/e^-$, serves also to dump the electrons and photons created initially in the target.

## RESULTS

Finally we have 4 scenarios which are primarily being investigated. For each one, the yield at the end of the first tank is calculated and given in Tab. 2. At the end of the first tank, the total yield – i.e. without any energy or transverse geometrical cut other than the cavity iris aperture – is much smaller for the approach based on the acceleration straight after the first tank. The use of the same S-band 2.856 GHz cavities but with a deceleration phase increases the yield. The highest yield is obtained for the approach using the L-band scenarios, being higher than 30%.

Table 2: The total yield for each scenario under investigation.

| Scenario (GHz) | Approach | Total Yield (%) |
|---|---|---|
| S-band (2.856) | acceleration | 3.5 |
| S-band (2.856) | deceleration | 8 |
| L-band (1.428) | deceleration | 37 |
| L-band (3.0) | deceleration | 33 |

One can appreciate the bunching efficiency of the approach using the TM020 (3.0 GHz) mode for the first tank with respect to the L-band only (1.428 GHz) on Fig. 5. This bunching for TM020 will result in a more efficient capture in the DR.

Although the total yield is a good indication of how well a technique performs with respect to one an other, to fully evaluate the impact of each scenario the positrons have be fully brought to the damping ring energy of 1 GeV where the energy cuts and geometrical cut can be apply to the requirements of the DR.

For this, a first study, including the acceleration up to the end of the 0.5 T solenoid, has shown that yields for positrons at 290±10 MeV are 4% and 29% respectively for the S-band 2.856 GHz and L-band 3 GHz. L-band room-temperature devices are not suitable to operate at very high fields so we set the gradient at 13 MV/m. Similar results were achieved using higher peak gradient (25MV/m) with a shorter accelerating capture section.

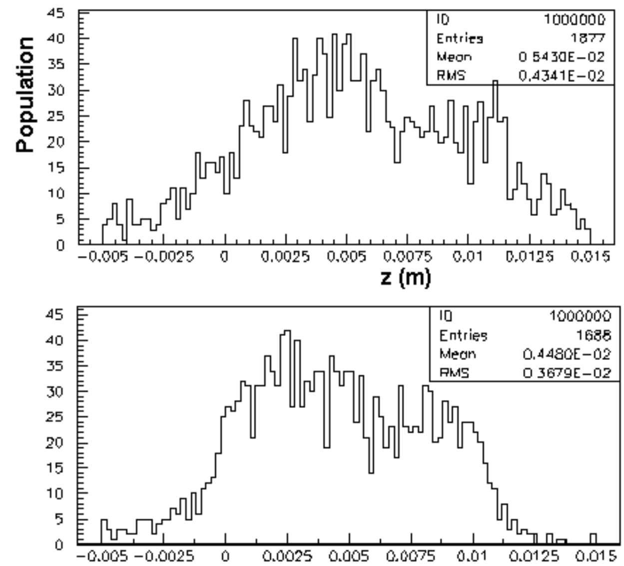


Figure 5: Longitudinal distribution at the exit of the first tank in the case of deceleration approach for the 1.428 GHz scenario (top) and the TM020 approach (bottom).

### *Prospective*

Assuming an approximate loss of two for the yield within the downstream FODO-based accelerating section, a 10 nC positron injector provide potentially slightly above 1.2 $10^9$ positrons for the S-band 2.856 GHz and 9. $10^9$ for the L-band TM020 scenario in the DR. These results take into account the energy acceptance of the damping ring.

## CONCLUSION

Several scenarios are being studied for the positrons capture and accelerating section. These scenarios are based primarily on the cavity phase tuned for deceleration and RF type of the first tank used for capture of positrons. Using deceleration and L-band type cavities in the first tanks helps to increase drastically the yield.

These studies indicate that the low energy solution for the SuperB positrons source can offer a good candidate to provide a sufficient and high quality positron beam.

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